RHIC AC Dipole Preliminary Study

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Requirements:

(1) Integrated dipole field =100 G-m @ 39 kHz;
(sometimes@ 60kHz)

Aperture -- limited by ceramic vacuum pipe 4” (ID)
with 0.25” thickness wall $\longrightarrow$ 4.5” (OD) = 11.43 cm
$\longrightarrow$ Clear bore: R = 6.0 cm (coils)

(2) Field quality – low E-3 field errors within R < 3 cm

Goals: dipole b1 ~ 100 Gauss (Lm = 1 m)
sextupole ratio b3/b1 ~ 1.5E-3 @ R=2 cm
3.4E-3 @ R=3 cm
obey scaling ~ (R/Ro)**2
(All cases in this study are achieved such quality)

Existing AC Dipole – Large current sheet type

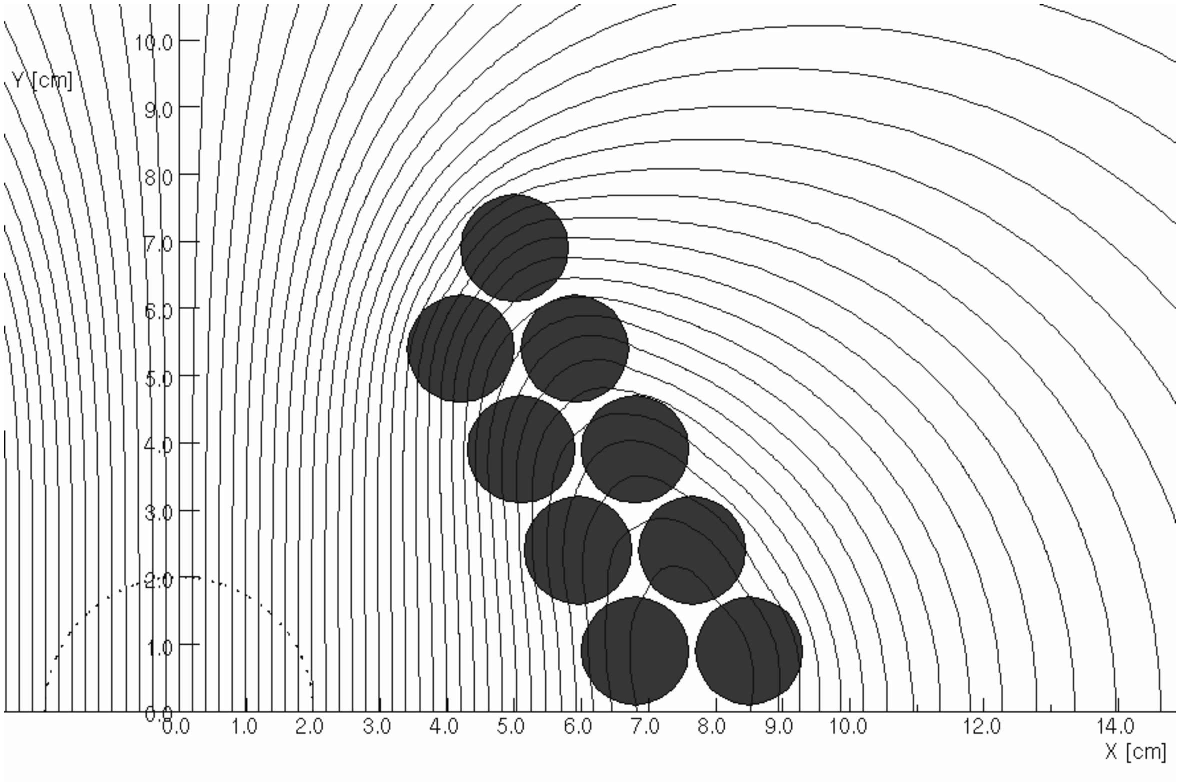
small aperture ~ R=1.5 cm; Io = 79 A

Good field quality (in 2d), but high inductance ~ 104 μH

Scaled from Existing One –

If we use similar conductor, more turns (N=8, or 9) are needed to build up enough height to achieve field quality.

Scaled from existing one – Air-coil



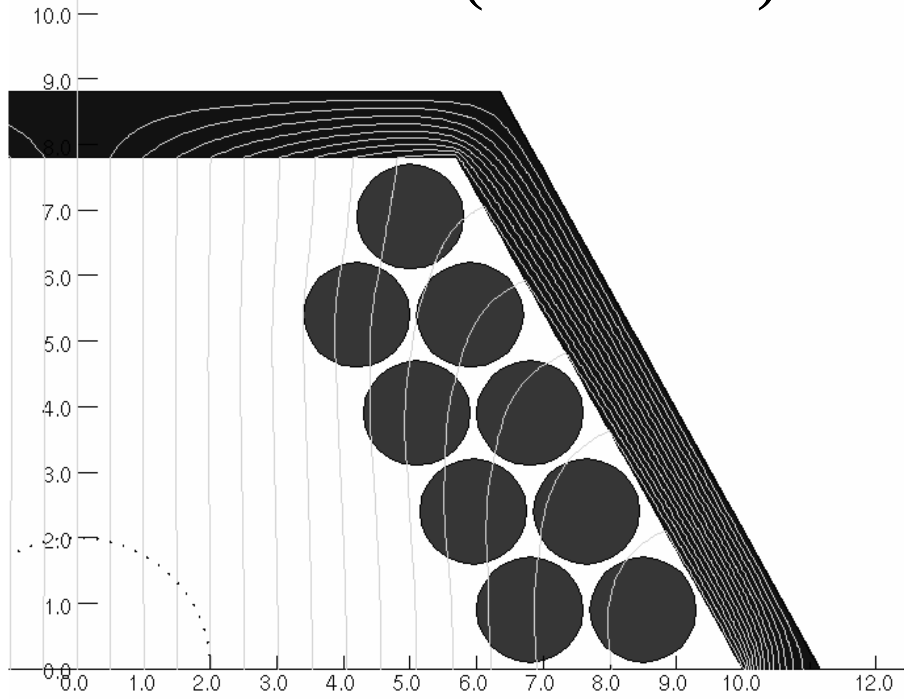
N = 9 (x2)

Io = 127.15 A

L = 153.7 µH

(per magnet with L_m=100 cm)

Scaled with Ferrite (CMD5005)



N = 9 (x2)

Io = 69.7 A

L = 296.4 μH

How to improve ?

Inductance can be reduced by reducing the number of turns

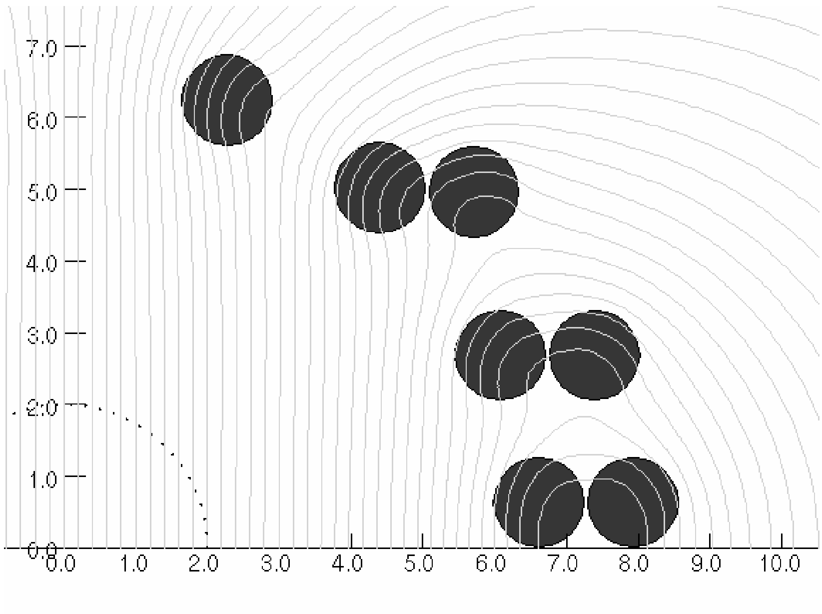
(I) Cosine theta type (with/without ferrite shell);

(II) Window-frame ferrite yoke, with thin Cu conductor;

(Cu skin depth: d = 0.33 mm @ 39 kHz)

(I) Cosine Theta Type -- N = 7 (x2) Air-coil

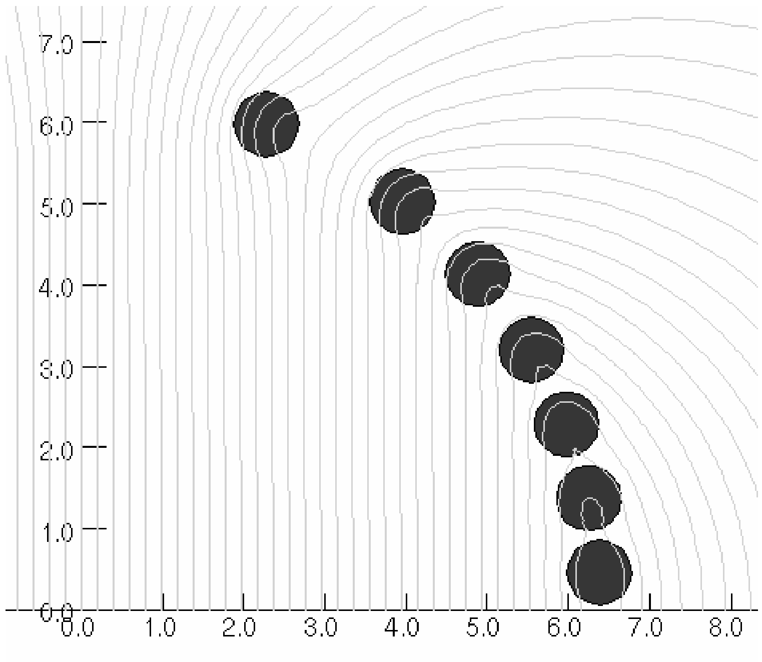
Two-layer



Io = 162.7 A

L = 90.7 μH

One-layer (small conductor)

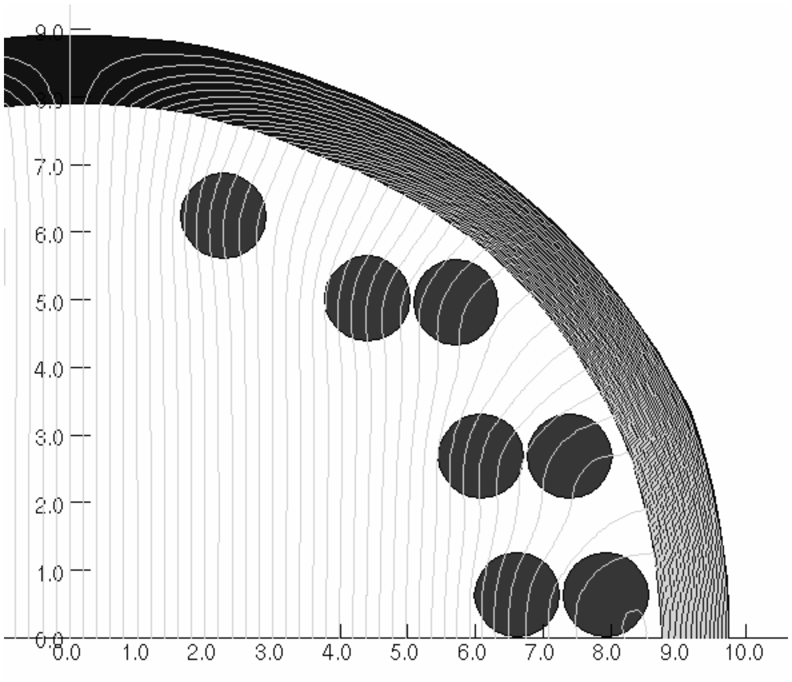


Io = 149.7 A

L = 93.3 μH

Cosine Theta Type -- N = 7 (x2) with Ferrite

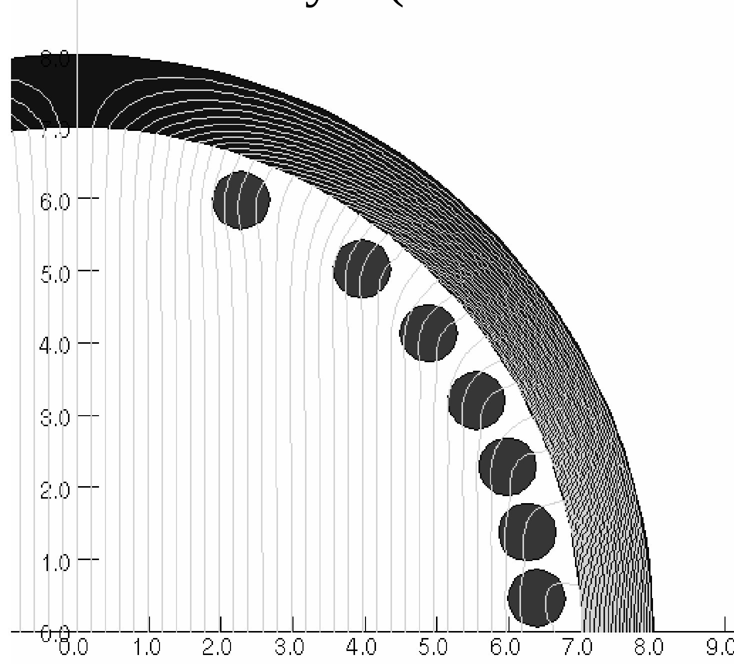
Two-layer



Io = 89.8 A

L = 171.1 µH

One-layer (small conductor)

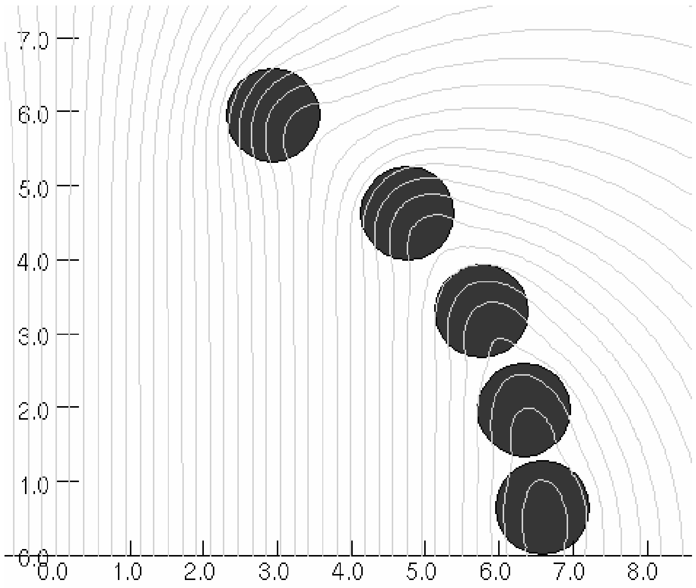


Io = 79.9 A

L = 175.8 µH

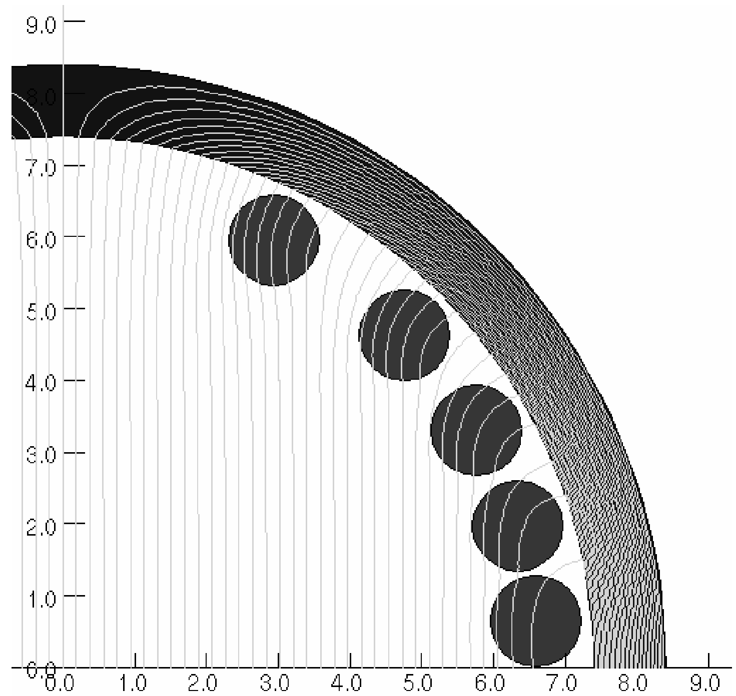
Cosine Theta Type – N=5 (x2)

Air-coil



Io = 223.0 A
L = 47.53 μH

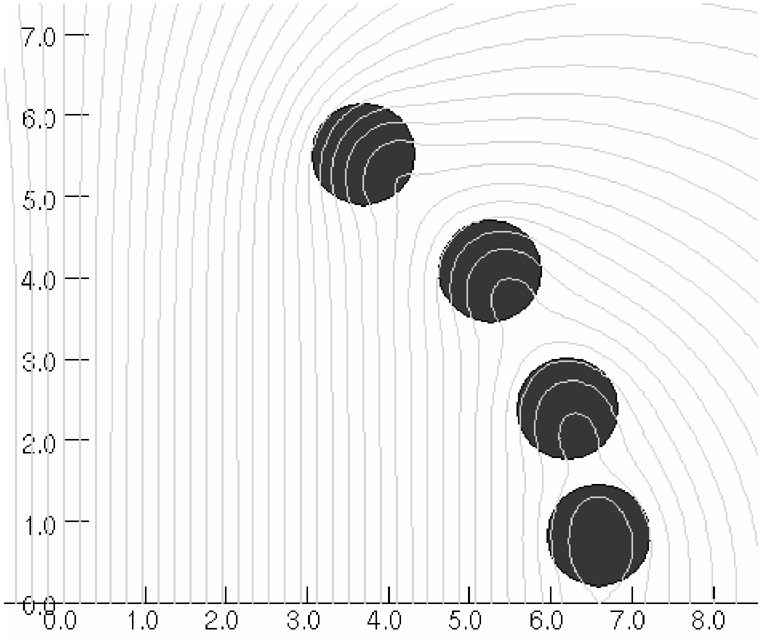
with ferrite



Io = 122.63 A
L = 88.9 μH

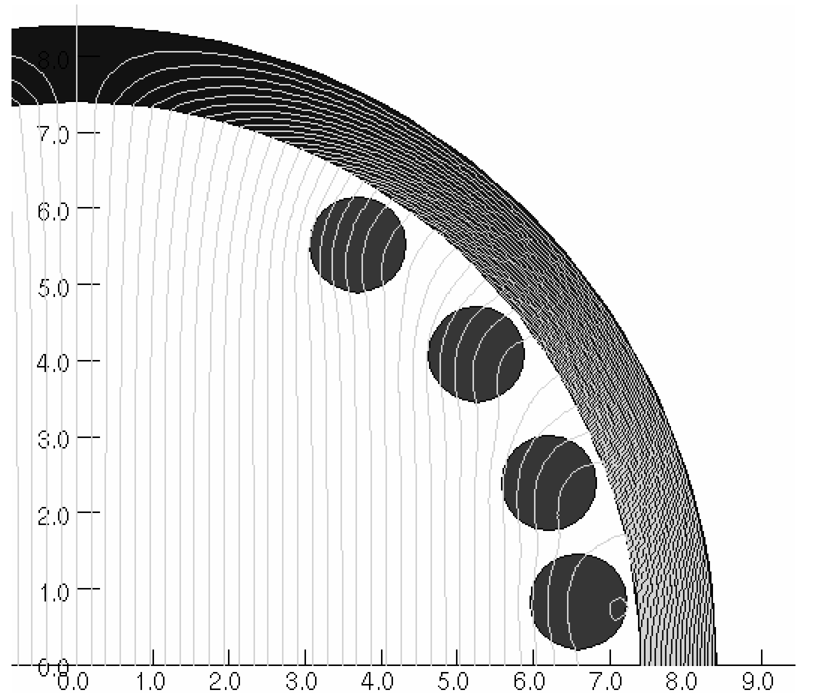
Cosine Theta Type – N=4 (x2)

Air-coil



Io = 264.7 A
L = 32.2 µH

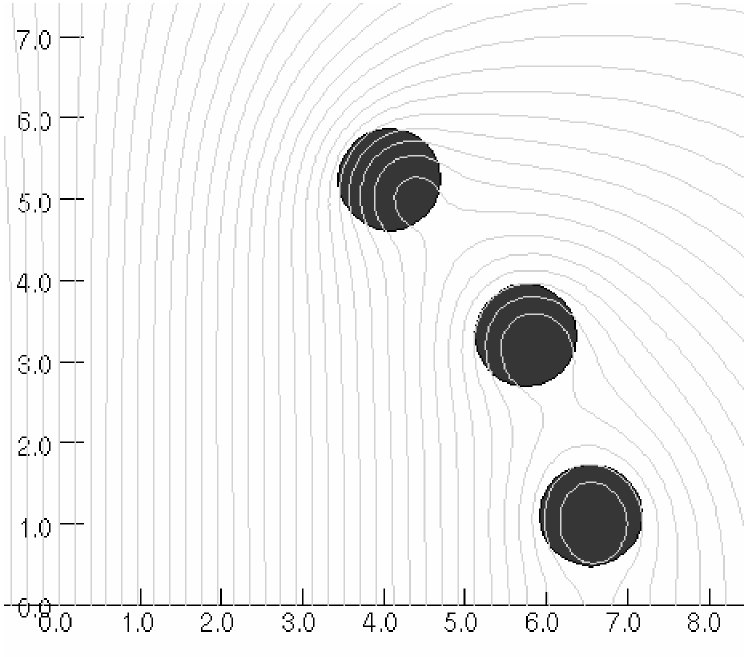
with ferrite



Io = 145.6 A
L = 60.4 µH

Cosine Theta Type – N=3 (x2)

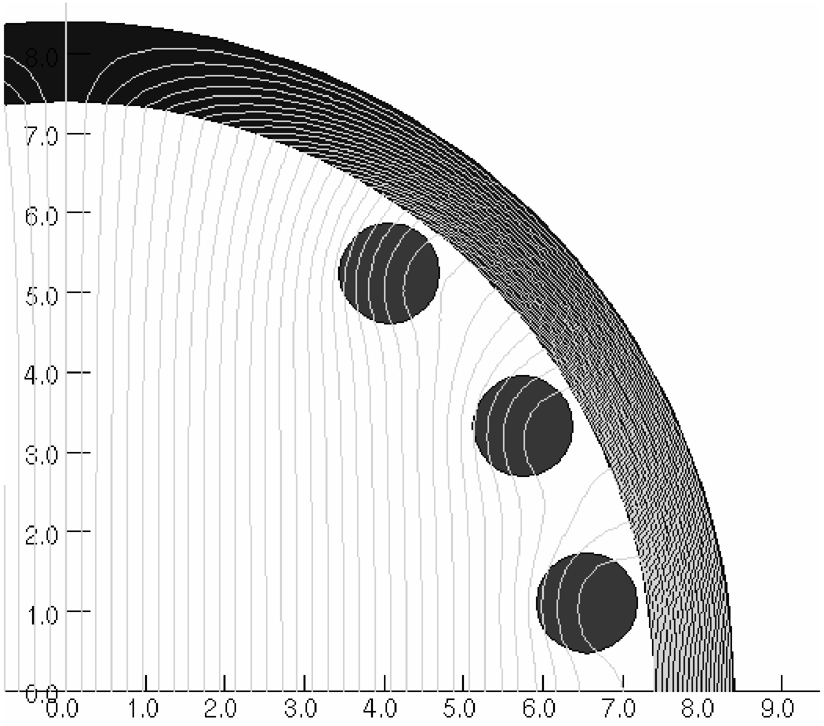
Air-coil



Io = 350.7 A

L = 18.8 μH

with ferrite

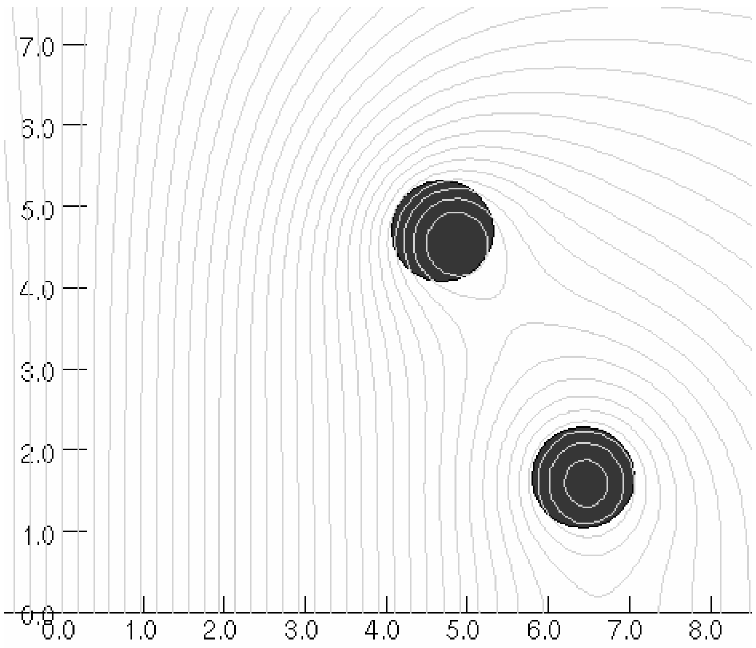


Io = 192.9 A

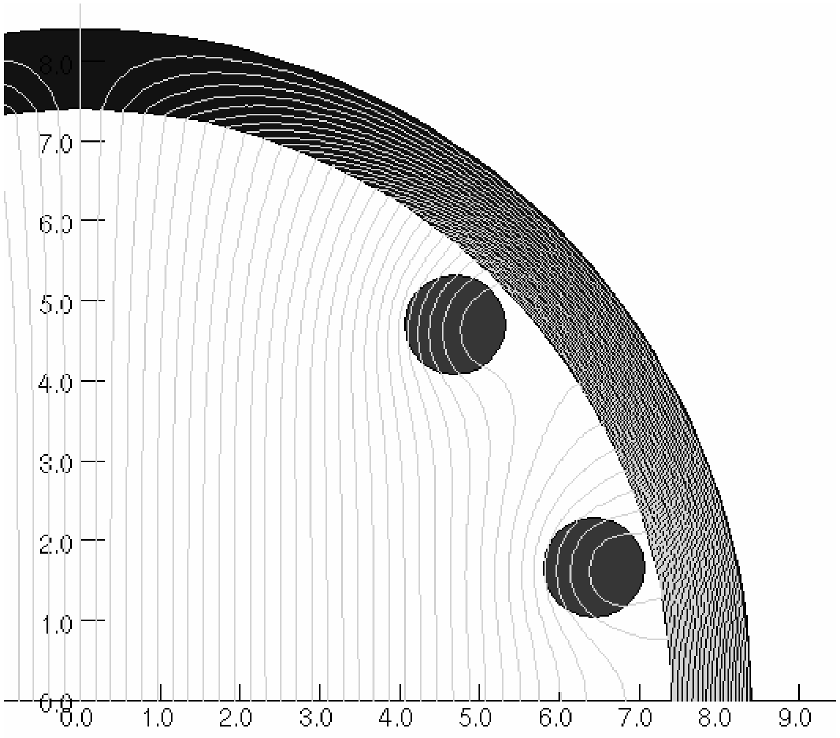
L = 34.8 μH

Cosine Theta Type – N=2 (x2)

Air-coil



with ferrite



Io = 517.3 A

L = 9.2 μH

Io = 284.5 A

L = 16.7 μ H

Cosine Type Summary --

(1) All the cases above (except cosine 7-turn one-layer) same conductors are used (as existing one: d=0.5”), tentatively

(2) Ferrite shell reduces current by a factor of ~ 0.52-0.55; increases inductance by a factor of ~ 1.9; it gives slightly better field, and will make internal field stable in the tunnel

(3) Comments ---

a. Less number of turns gives smaller inductance, but requires tights tolerance on conductor position random errors;

b. Real conductor (Litz wire) may contribute additional error due to the deformation of the strand/bundle;

c. Preference: with Ferrite shell (?).

(II) Window-frame Type –

N=1 (x2)

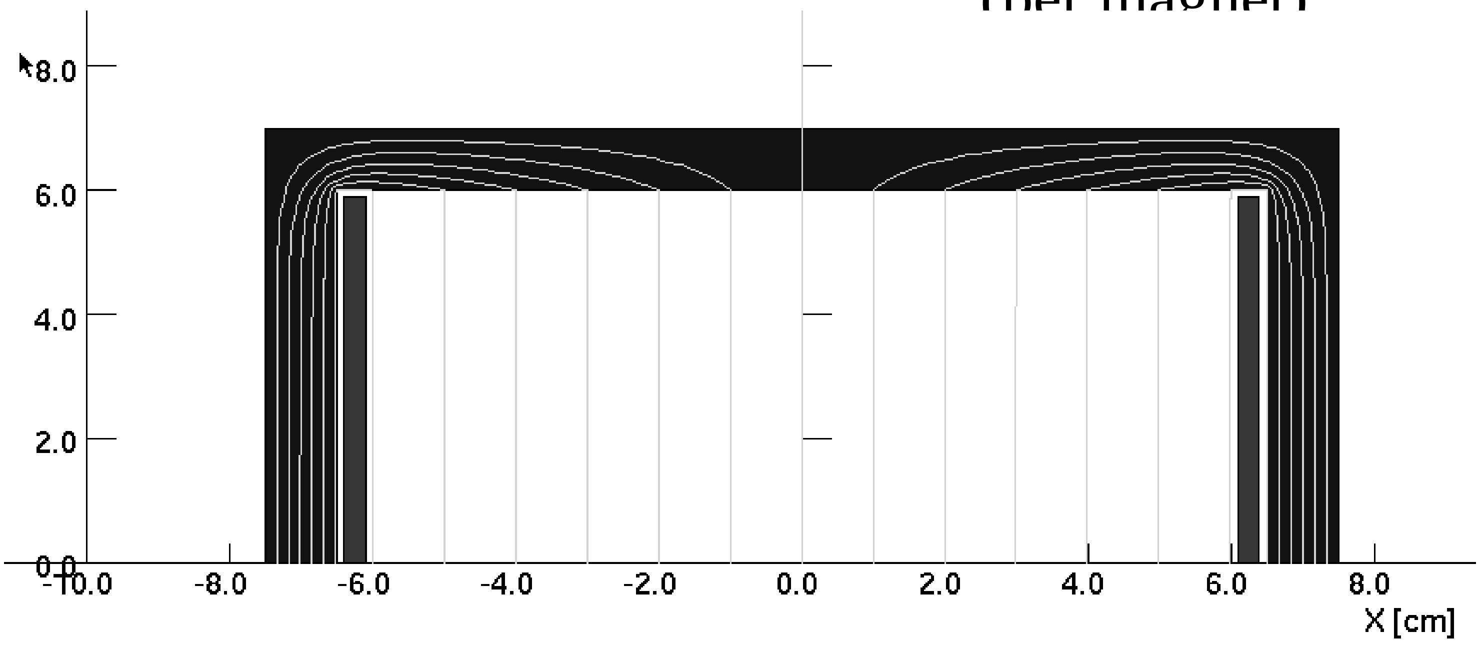
Io = 480 A

L = 5.1 μH

If use solid Cu stripes, loss in conductors: 400 W (39 kHz);

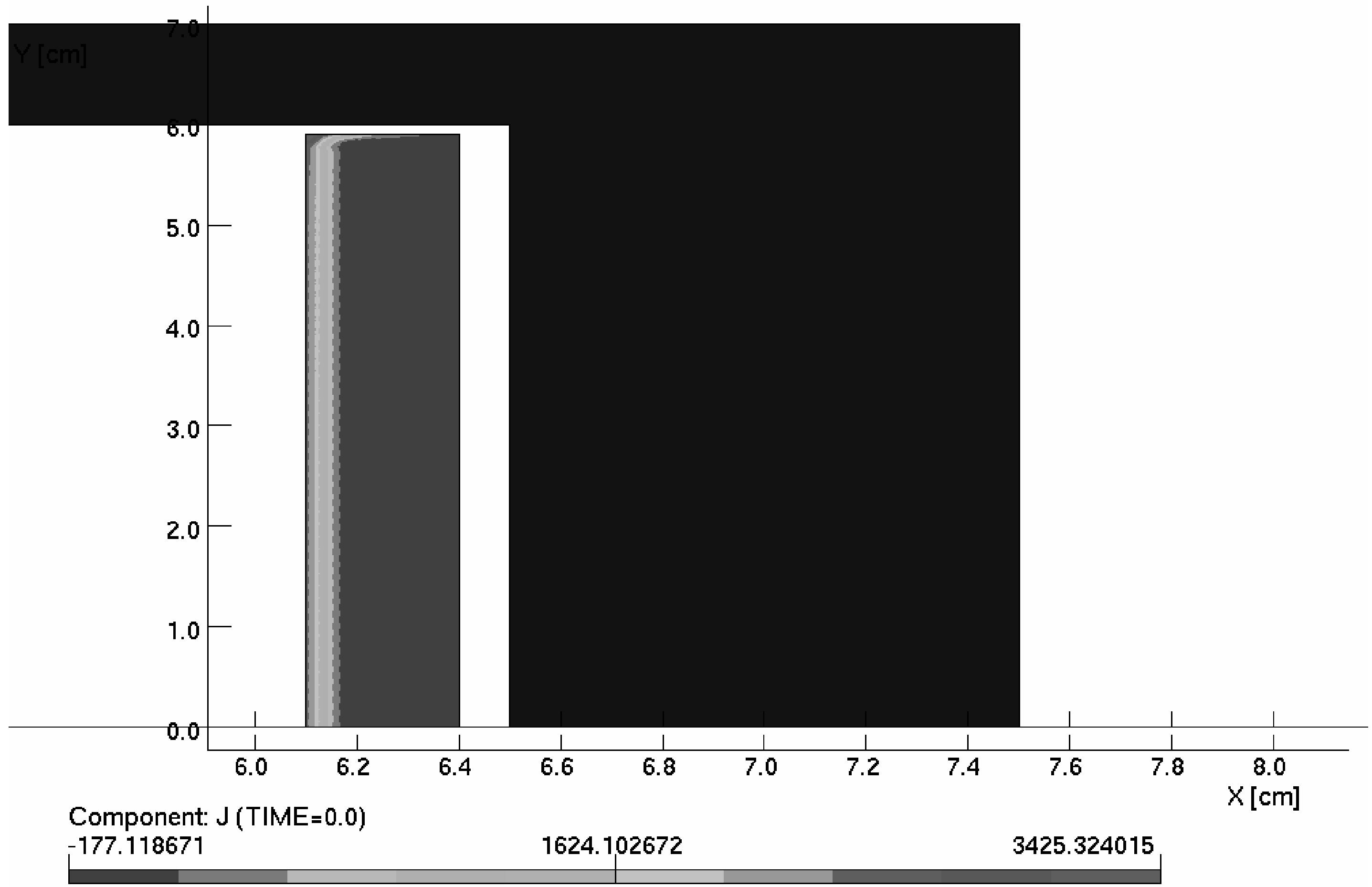
(P = ?J^2/s ds) 480 W (60 kHz)

(per magnet)



Current density distribution in the Cu conductor (f = 39 kHz)

$I(t) = 480 * \cos(2p\ f\ t)$



(A/cm^2)

Window-frame Type Summary –

(1) It gives good field control and small inductance;

(2) The loss in the Cu conductor is an issue…